Copy 1

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

ORDCIT Project
Contract No. DA-04-495-Ord 18
Department of the Army
ORDNANCE CORPS

External Publication No. 490

SATELLITE TRACKING

Eberhardt Rechtin

Copy No.

JET PROPULSION LABORATORY
California Institute of Technology
Pasadena 3, California
May 15, 1958

External Publication No. 490

SATELLITE TRACKING[1]

Eberhardt Rechtin

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

INTRODUCTION

By this time most engineers have become familiar with the radio tracking of satellites as accomplished by the Minitrack stations. In addition to Minitrack stations there is a small network of Microlock stations designed to pick up telemetering from the Explorers. The locations of these stations are shown on the following world map.

(Slide 1. World Map with Locations of Microlock and Minitrack Stations)

Generally speaking, the complete network has performed its job as designed. This talk is therefore about the unexpected phenomena which materialized in satellite tracking.

THE RUSSIAN SATELLITE

The first unexpected occurrence, of course, was the fact that a Russian satellite was orbiting instead of a U. S. satellite. To the radio-tracking specialist, the most significant difference between the two was the transmitting frequency, the Russians using 20 and 40 mc as compared with the U. S. frequency of 108 mc. The Russians

[1]This paper presents the results of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under Contract No. DA-04-495-Ord 18, sponsored by the Department of the Army, Ordnance Corps.

chose 20 and 40 mc to gain propaganda effect and to study the ionosphere.

The propaganda effect we know, but the ionospheric effects were often quite strange. For example, radio waves would be trapped under the ionosphere as shown in the following slide.

(Slide 2. Trapping of 20-mc Radio Waves by the Ionosphere)

As a result of this trapping it was possible for stations far removed from the satellite path to hear the satellite for considerable lengths of time, reports of from 1/2 hour through almost 1 1/2 hours being fairly common. One of the more curious effects noted by the ground-station listeners was that of a precursor to the expected satellite signals. This precursor is shown in the next slide.

(Slide 3. Precursor Signal)

Very small, low-level signals would appear about 30 seconds before the main satellite signal. This precursor signal was a reasonably reliable warning that the satellite was about to appear. The precursor was probably caused by an ionospheric trapping effect creating rings of reception with the satellite at the center. These rings are shown on the following slide.

(Slide 4. Rings of Reception of Satellite at 20 mc)

These signals could, of course, be tracked by interferometer or direction-finding techniques to determine the direction of arrival. Knowing that the satellite was going approximately 18,000 miles per hour, it was possible to state which signals were coming from a satellite on a nearly overhead pass and which signals were coming from satellites on the further rings.

There was a most interesting exception to this kind of reception: a so-called ghost satellite, illustrated in the following slide.

(Slide 5. Ghost Satellite)

Under certain conditions it was possible to have a signal show up on the earth 180 degrees away from the true position of the satellite. In spite of the fact that the satellite was on the other side of the earth, the signals had much the same characteristics as if it had been overhead; they would even reproduce an interferometer pattern. A possible explanation is that the radio waves were trapped by the earth's magnetic field or were trapped in a rather peculiar way by the ionosphere so that they reached the listener in precisely the right phase. This particular effect was observed at 40 mc. It was reported by Dr. W. H. Wells of the Carnegie Institute of Washington in the March, 1958, issue of Institute of Radio Engineers.

Still another ionospheric effect made it appear as if the vehicle were spinning or tumbling. The effect would have been real except that the spin rates would often increase and decrease within a given pass, and from pass to pass they were not the same. The effect on the ground was such as to put deep fades into the signal at near-periodic intervals. A typical example is seen in the next slide.

(Slide 6. Typical Sputnik Fade Pattern on 20 mc)

The timing between the various fades varied considerably. Periods of between 15 seconds and 15 milliseconds were observed. The rate of increase of the periods depended upon whether the Sputnik was approaching the magnetic pole or traveling parallel to it.

The situation was further confused by having an unknown type of telemetry aboard the Russian satellites. Not all passes were made with the same kind of telemetry. For example, at one time there was frequency modulation on certain of the Sputnik II passes. A typical example is given in the following slide. Misinterpreted, such data could make it look as though there were a most peculiar doppler motion of the vehicle.

(Slide 7. Frequency Modulation of Sputnik II)

EXPLORER I

It is fair to say that the signals received from Explorer I were not of the strengths expected beforehand. On the basis of a relatively undirectional pattern and a spinning cylindrical form, it was expected that a relatively constant sig uld be obtained, with only a small amount of modulation being ... to the spin itself. Instead of this, the signal had fades roughly every 7 seconds which increased in depth from the initial injection point until they reached a fairly stable action some days later. The radio signals made it appear as if the spinning body had rapidly slowed down in spin rate and had built up a propeller-like motion at the same time. The damping of the propeller-like motion was very small compared to the damping of the spin rate. The following slide shows a typical flight record.

(Slide 8. Post-Launch Signal Strength of Explorer I Compared with Signal Strength Observed Several Days Later)

It turned out that this effect can be predicted by physical considerations, once you think of them. The effect is something like this: In a rigid body, one in which there are no internal losses, there are two stable spin modes. The first spin mode is around the axis of maximum angular inertia. The second spin mode is around the axis of minimum angular inertia. For a cylindrical shape, these two modes are either spinning like a rifle bullet or whirling like a propeller. The addition of turnstile antennas would change the particular angular inertia somewhat, but would not change the two stable spin modes. However, if there are losses in the system, such as the losses due to the shipping of the turnstile antennas, there is only one stable mode. This mode is about the maximum angular inertia, i.e., whirling like a propeller. Thus, a body which starts out like a rifle bullet ends like a propeller. This is shown in the following slide.

(Slide 9. Transition from Spin to Propeller Motion)

We also learned some interesting things about instrumenting for outer space, one of the most important being that you should believe your instruments rather than your preconceived ideas of physics. For example, in the cosmic ray counter for Explorer I, it was thought that certain data taken by the Singapore and Nigerian bases were of no value. The reason for thinking this was that the cosmic ray telemetering channel seemed to be behaving improperly. The records seemed to have no counts at all or else were noisy at certain times over these stations. One assumption was that the receiving equipment wasn't working properly. At other times, over these same stations, reception would apparently be satisfactory. As we later found out,

the counter was working properly but was badly saturated. Under moderate saturation conditions, the total count was high enough to have no remaining output from the channel. When the count got higher, the channel became noisy. This phenomenon was later duplicated on the ground. The reason that certain passes were better than others was found to be a strong function of altitude. As Dr. van Allen will report, in a much more scientific vein, a tremendously high count was registered at extreme altitude over the magnetic equator. This particular data could not be cross-checked until Explorer III was in orbit.

The ionospheric effects on 108 mc were considerably less marked than those on 20 and 40 mc. Many of the effects had been expected from earlier firings.

One of the strangest things to occur in Explorer I was the resurgence of an apparently dead transmitter. The higher-power transmitter from Explorer I had the following power output vs time curve.

(Slide 10. Explorer I Power Output vs Time, High-Power Beacon)

As can be seen, the transmitter experienced a relatively normal life cycle for the first several weeks. The resurgence at a later time was not expected. The reason for the resurgence is shown in the following slide.

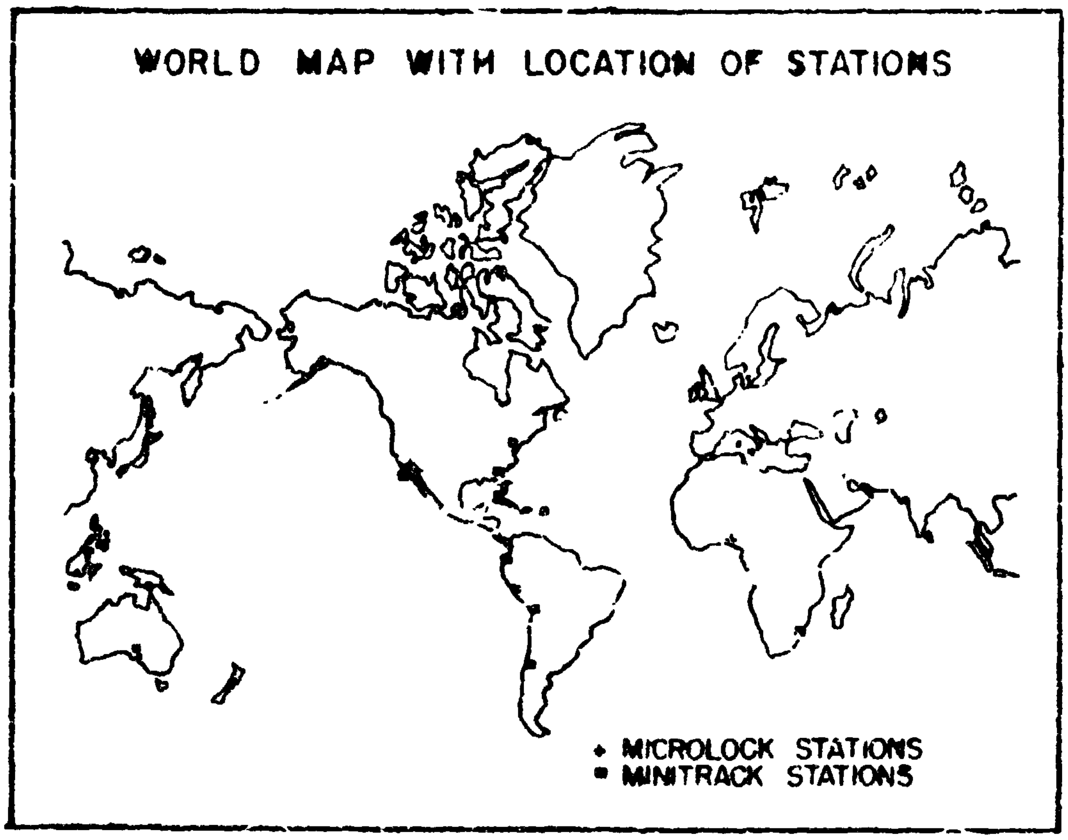
(Slide 11. Circuit Diagram for Explorer I High-Power Beacon Transmitter)

Battery A gradually weakened and finally reached a point where oscillations could no longer be maintained. The power output of the transmitter then stopped, but current continued to flow in the circuit and a small back voltage continued to be produced by resistance of the battery. Eventually, sufficient mercury was produced in the battery to reduce the battery resistance to zero, and the second battery, Battery B, could attempt to drive the circuit without the drag of Battery A's resistance. The efficiency of such a mode of operation is lower than that under proper operation. The transmitter lasted until the second battery was also exhausted.

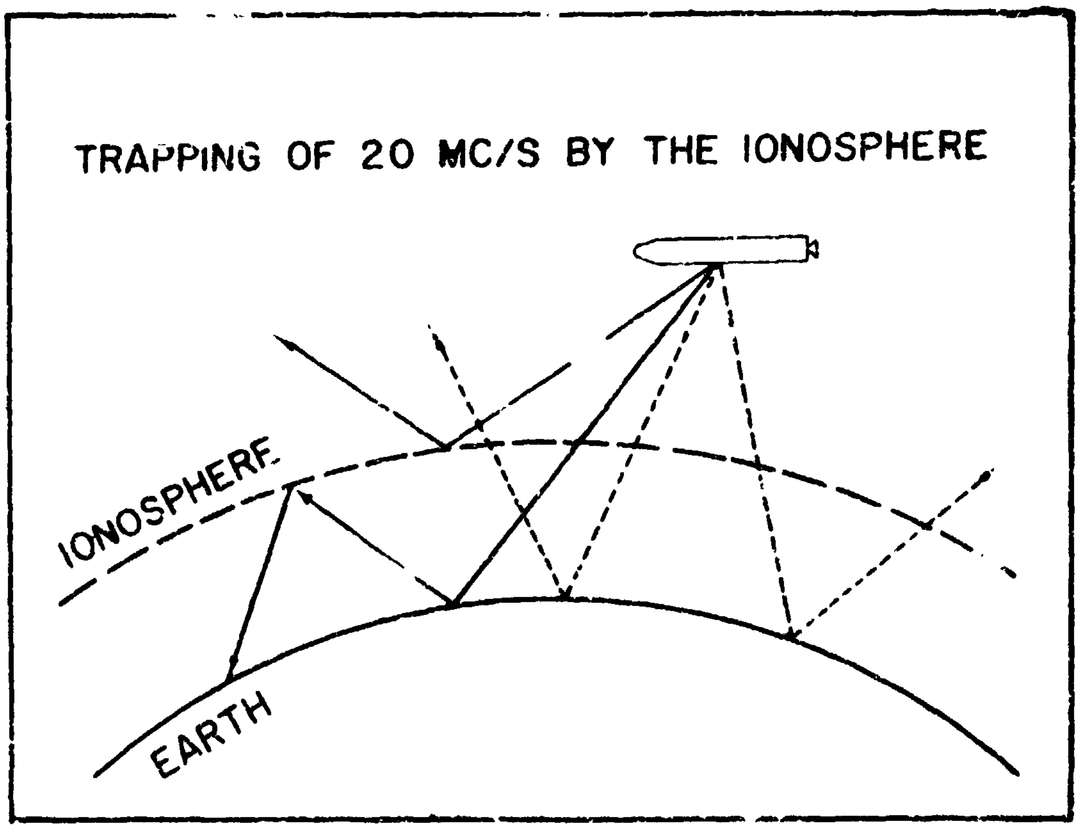
I'm not sure what this proves, other than that when you do life testing you should do it long after your unit is dead. I also don't know whether or not Vanguard I had a like experience, although it employed a similar transmitter with chemical batteries.

FUTURE SPACE VEHICLES

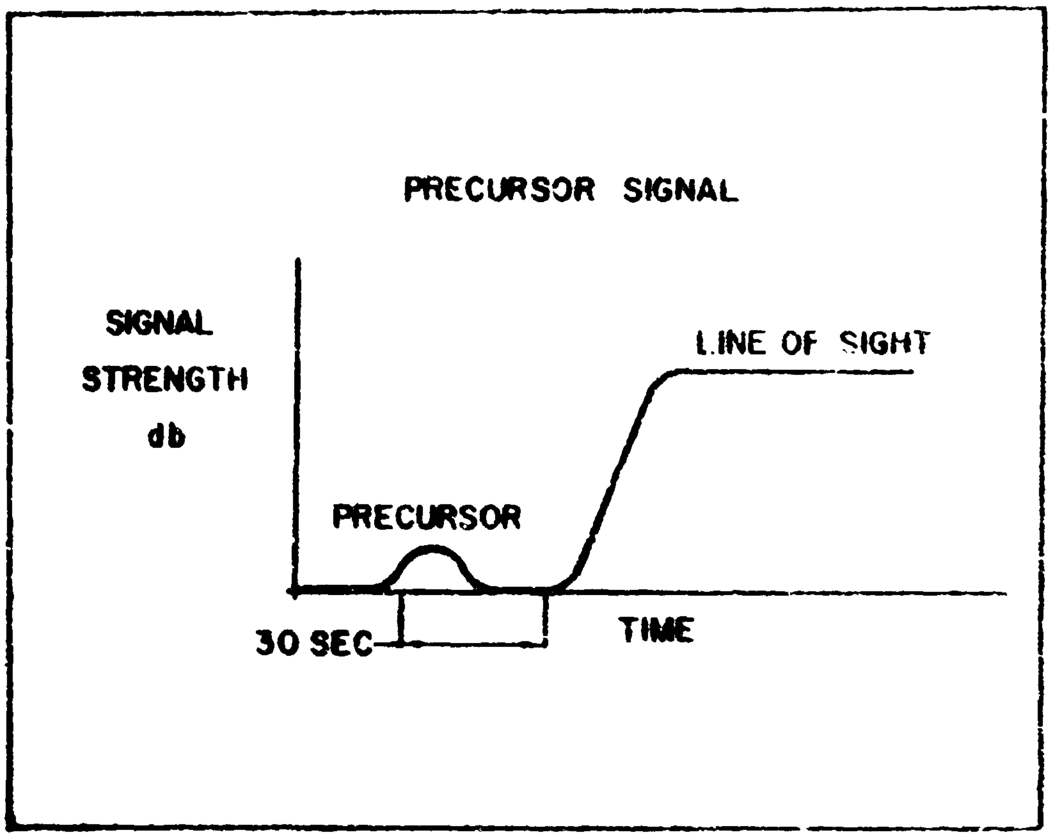
It is a safe bet that we have not seen the end of unusual tracking phenomena. For example, theorists have postulated an equatorial current existing at several earth radii, composed of millions of amperes of charged particles moving in a generally westerly direction. Other theorists have said that the moon will have an ionosphere, even though its atmosphere is necessarily limited. In addition, our earth-bound thinking often inhibits the consideration of physical phenomena in a perfect vacuum under free-fall.



Slide 1. World Map with Locations of Microlock and Minitrack Stations

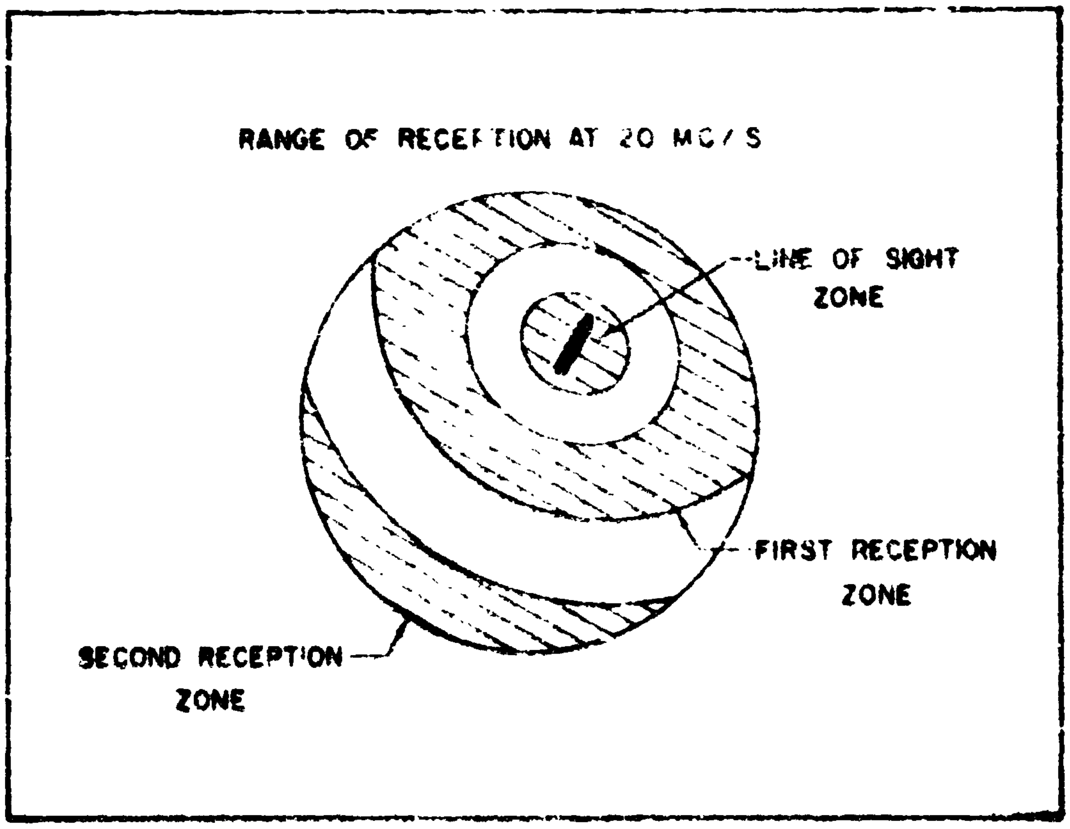


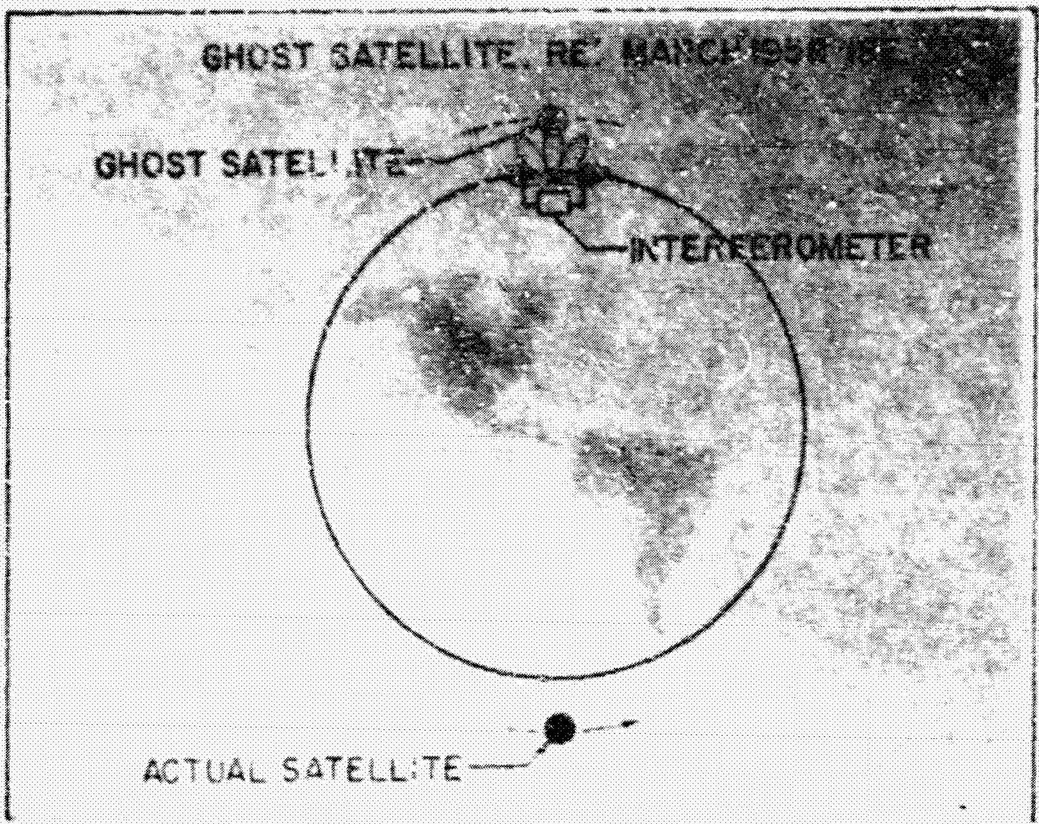
Slide 2. Trapping of 20-mc Radio Waves by the Ionosphere



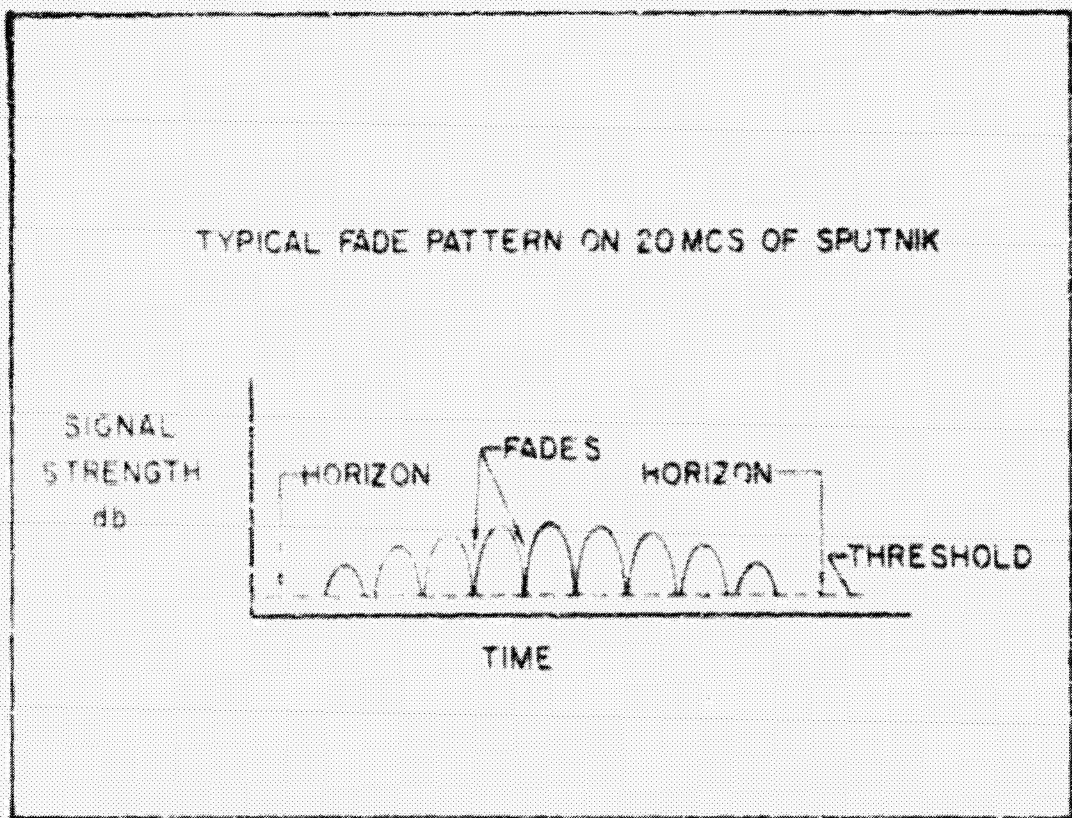
Slide 3. Precursor Signal

Slide 4. Rings of Reception of Satellite at 20 mc

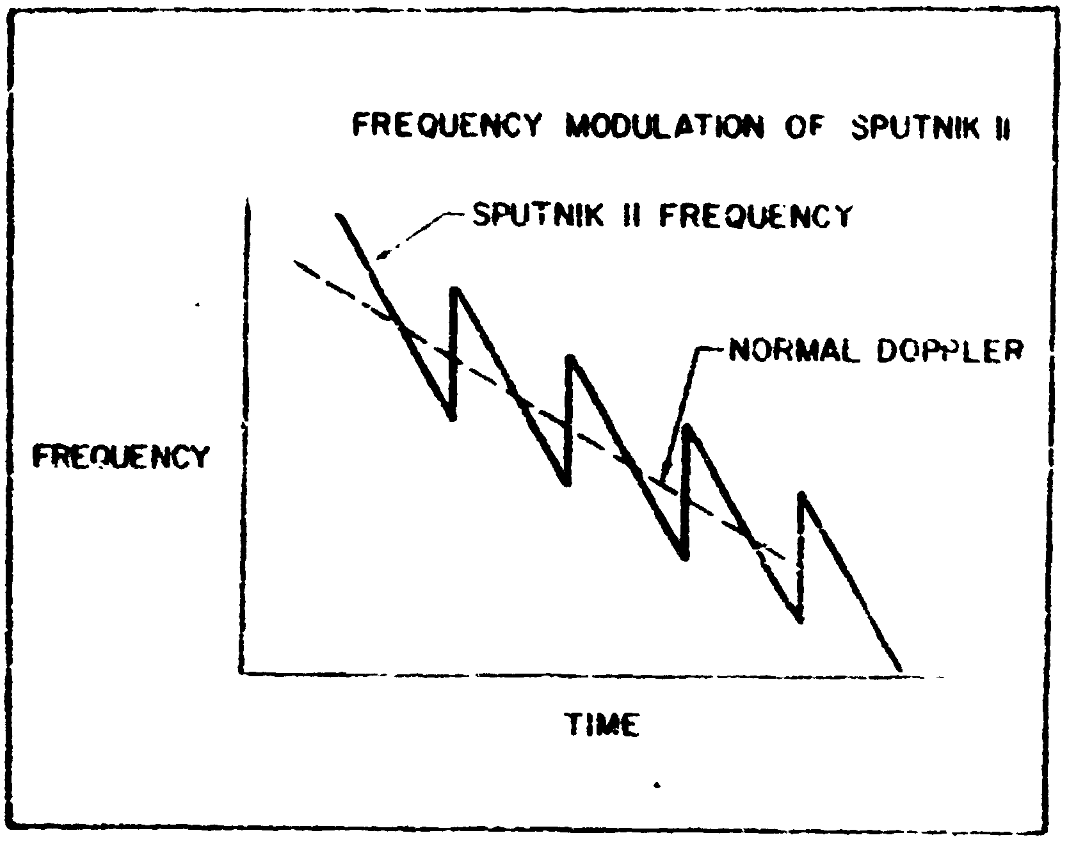




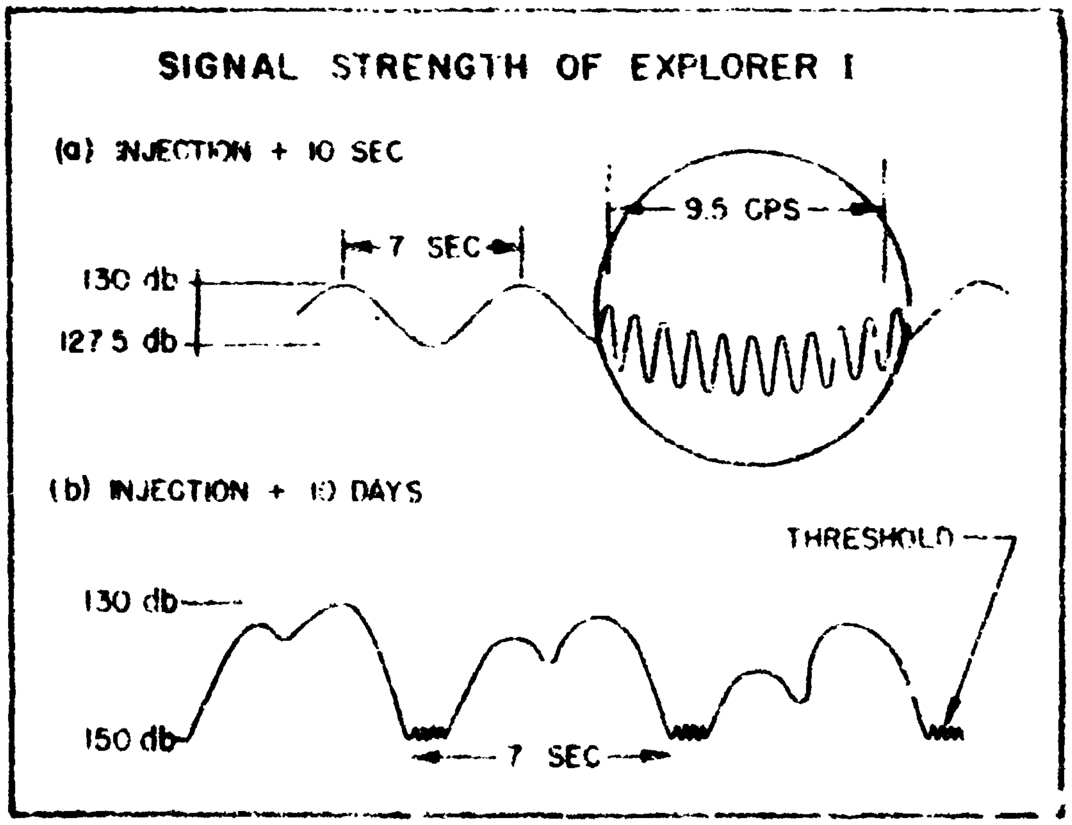
Slide 5. Ghost Satellite



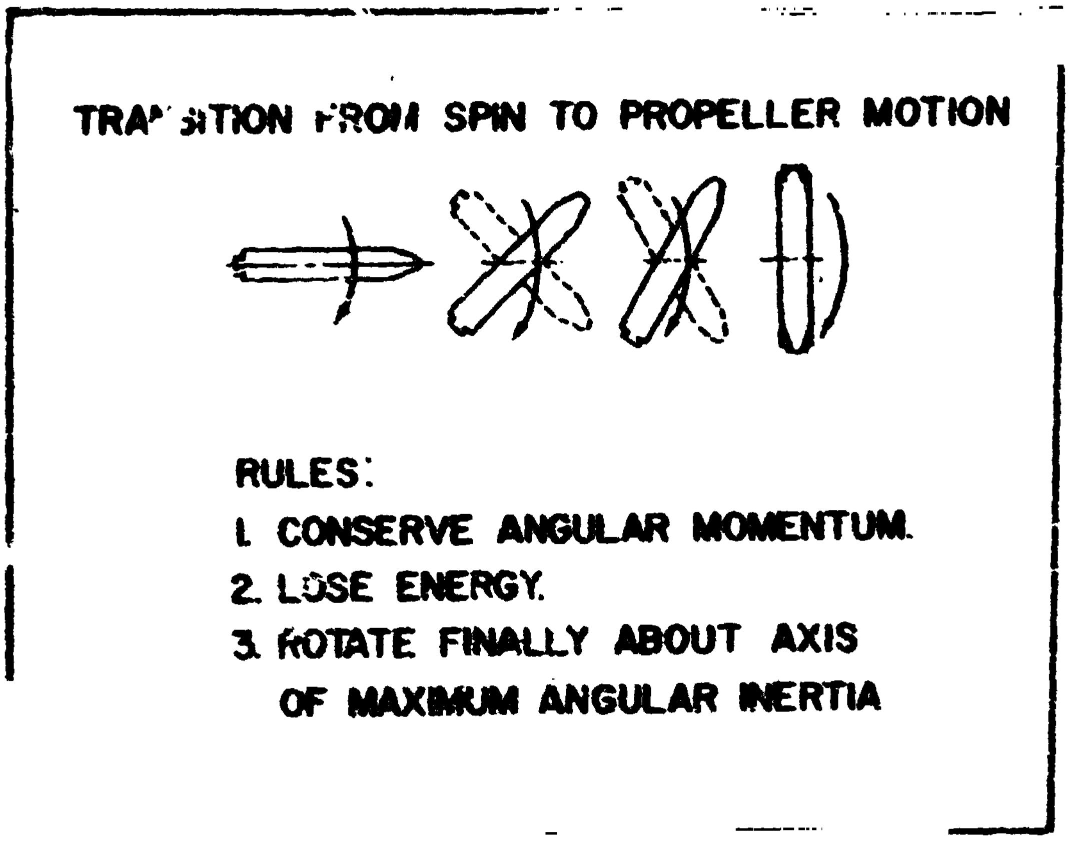
Slide 6. Typical Sputnik Fade Pattern on 20 mc



Slide 7. Frequency Modulation of Sputnik II

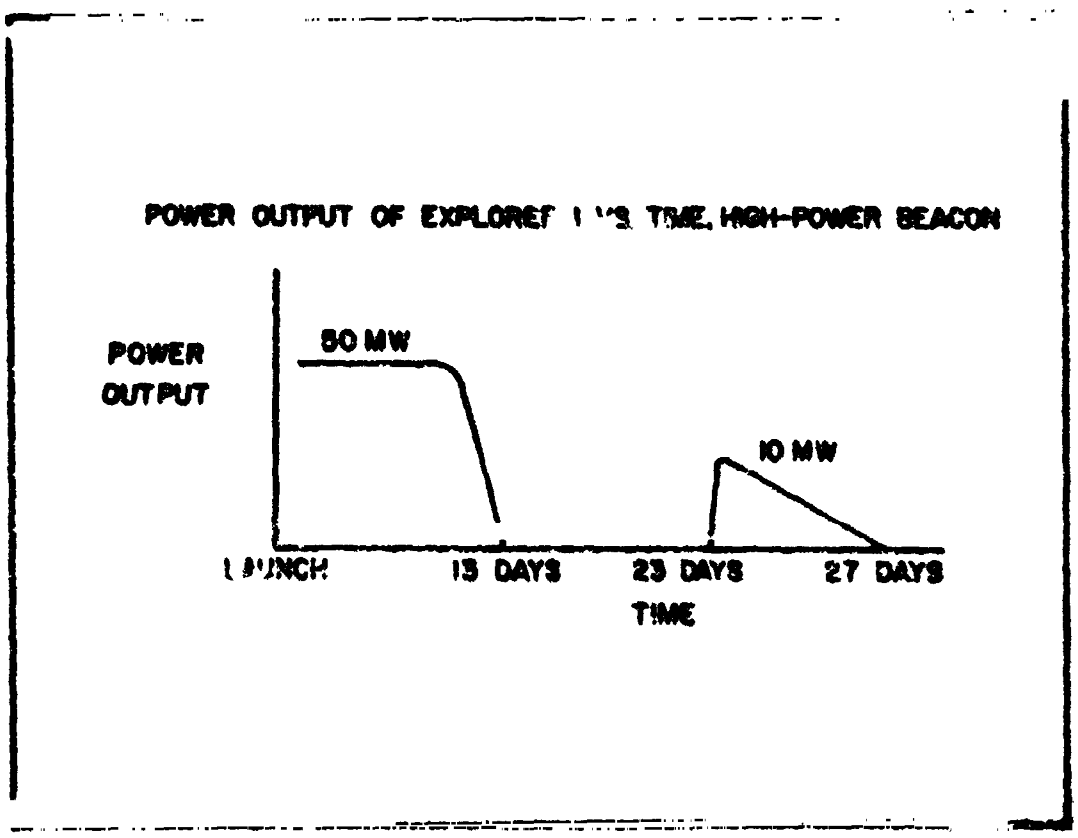


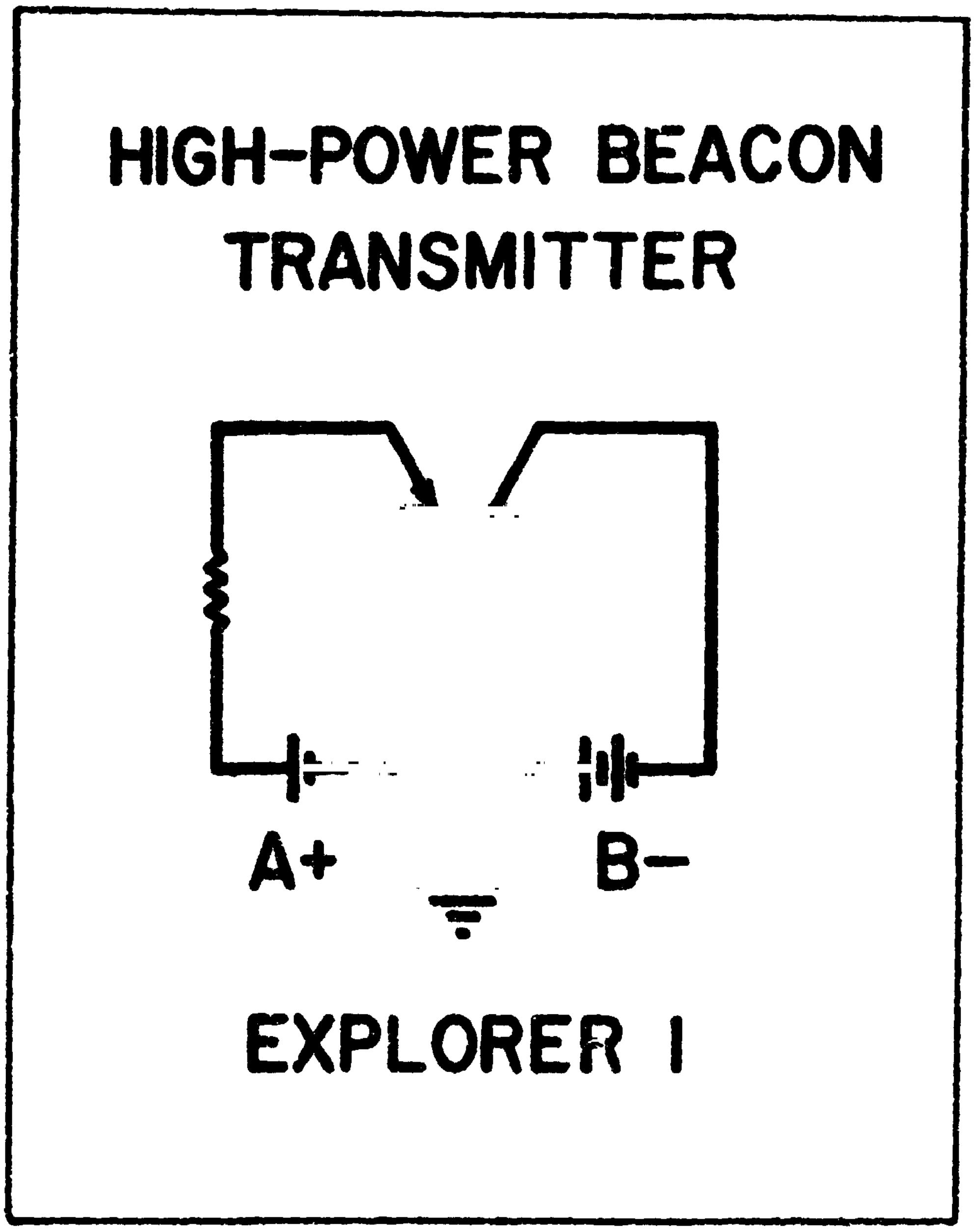
Slide 8. Post-Launch Signal Strength of Explorer I Compared with Signal Strength Observed Several Days Later



Slide 9. Transition from Spin to Propeller Motion

Slide 10. Explorer I Power Output vs Time, High-Power Beacon





Slide 11. Circuit Diagram for Explorer I
High-Power Beacon Transmitter)